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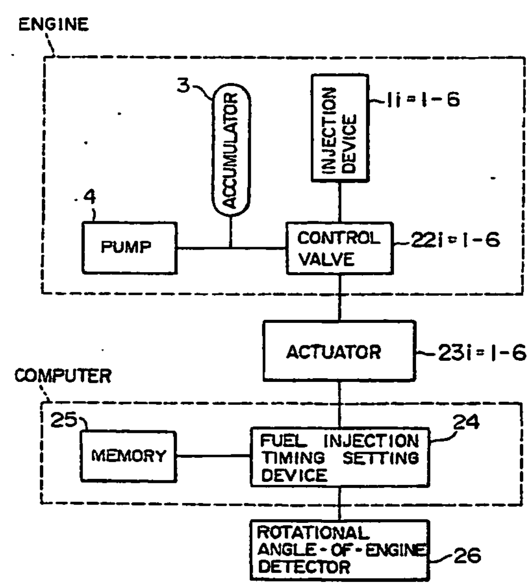
(54) Apparatus for suppressing torsional vibration of a crank shaft of a diesel engine.

(57) A suppressing apparatus of torsional vibration of a crank shaft of a diesel engine can effect suppression of a resonant stress by only adjustment of a fuel injection system.

The suppressing apparatus of torsional vibration of the crank shaft of the diesel engine adjusts a fuel injection timing and a fuel injection period (injection amount) for each cylinder in the vicinity of a resonant point of torsional vibration properly and varies a characteristic curve of pressure in the cylinder with respect to a crank angle to reduce the magnitude of harmonic components of resonance order of torque added to each cylinder, or adjusts phase differences of the harmonic components for each cylinder and suppresses the resonant stress so as to cancel external force for the vibration mode.

F I G. I



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FIELD OF THE INVENTION AND RELATED ART STATEMENT

The present invention relates to an apparatus for suppressing torsional vibration of a crank shaft of a diesel engine.

As shown in Fig. 8, a fuel injection apparatus 7 of a conventional diesel engine is driven by a cam 6 and a roller 5 and is structured to inject fuel into each of the cylinders at the same injection timing and period of time.

Suppression of resonance stress of torsional vibration in a crank shaft system of a diesel engine equipped with a conventional injection apparatus is made by change of a length and/or a diameter of the shaft system, addition of further mass or mounting of a torsional vibration damper. For example, in the case of a diesel engine for a ship having six cylinders, as shown in Fig. 4, a one-node six-order resonance point 16 of torsional vibration exists within an ordinary operation range. Accordingly, a relatively wide operation avoidance area is established. Consequently, since an operable range of rotational number is limited, steering is often inconvenient. Suppression of the one-node six-order resonance stress is made by making the diameter of the shaft extremely large to increase the resonant point to a high rotation side, by attaching extremely large mass to a front end of an engine to reduce the resonant point to a low rotation side, or by providing an expensive torsional vibration damper. Accordingly, large modification of design and cost are required.

OBJECT AND SUMMARY OF THE INVENTION

It is an object of the present invention to provide a suppressing apparatus of torsional vibration of a crank shaft of a diesel engine capable of suppressing the resonant point stress only by adjustment of a fuel injection system.

In order to achieve the above object, the suppressing apparatus of torsional vibration of the crank shaft of the diesel engine adjusts a fuel injection timing and a fuel injection period (injection amount) for each cylinder in the vicinity of a resonant point of torsional vibration properly and varies a characteristic curve of pressure in the cylinder with respect to a crank angle to reduce the magnitude of harmonic components 12 and 13 of resonance order of torque 11 added to each cylinder, or adjusts phase differences 14 and 15 of the harmonic components 12 and 13 for each cylinder and suppresses the resonant stress so as to cancel external force for the vibration mode.

More particularly, the above problem in the prior art is solved by the following apparatus:

A suppressing apparatus of torsional vibration of a crank shaft of a diesel engine having a fuel injection mechanism capable of freely setting a fuel injection timing and period comprises a detector of a rotational number of the engine, and a fuel injection setting device for judging whether the detected value is within an area in the vicinity of a resonant point of torsional vibration of a crank shaft system or not to vary the fuel injection timing and period by a predetermined value if the detected value is within the area.

A fundamental principle of the present invention is as follows:

The magnitude of stress in the resonant point of torsional vibration of the diesel engine is proportional to the magnitude of a vector sum of the harmonic components 12 and 13 of the resonant order of the torque 11 added to each cylinder. Accordingly, if the magnitude of the harmonic components 12 and 13 of the resonant order and the magnitude of the vector sum are reduced in the resonance, the resonant stress can be suppressed.

The fuel injection timing and period are properly varied to adjust the characteristic curves 8 and 9 of pressure in the cylinder for each cylinder so that the harmonic components of torque produced in each cylinder is decreased and the vector sum is made small to reduce the resonance stress.

The effects of the present invention are as follows:

The present invention makes it possible to reduce the excitation torque component in the vicinity of the resonant point of torsional vibration of the crank shaft by modification of the fuel injection period in the diesel engine. Since the additional stress by the resonance in the vicinity of the resonance point is reduced, the operation avoidance area is made narrow and can be removed if circumstances require. Further, suppression of resonance requiring the provision of the torsional vibration damper can be effected by only adjustment of the fuel injection system.

Since the suppression of resonance by this method depends on reduction of the excitation force, effect can be exhibited for not only one node but also every vibration mode such as two nodes.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a block diagram of a suppressing apparatus of torsional vibration in a crank shaft of a diesel engine according to the present invention;

Fig. 2(a) is a diagram showing a characteristic curve of a pressure in a cylinder versus a crank angle;

Fig. 2(b) schematically illustrates a crank mechanism;

Fig. 3 shows harmonic component in variation of torque with respect to a crank angle;

Fig. 4 is a diagram showing a resonance curve of additional stress of torsional vibration versus the rotational number of an engine;

Fig. 5 is a diagram showing one-node torsional amplitude mode;

Fig. 6 is a flow chart 1 of a suppressing apparatus of torsional vibration;

Fig. 7 is a flow chart 2 of a suppressing apparatus of torsional vibration; and

Fig. 8 is a schematic diagram illustrating a general fuel injection system.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Embodiments of the present invention having six cylinders are now described in detail with reference to Figs. 1 to 8.

A configuration of a first embodiment is now described. Stress produced in a crank shaft in operation in a resonance of torsional vibration or in the vicinity thereof is proportional to a magnitude of a harmonic component of the resonant order of a composite torque of an engine producing vibrating force. In the present invention, the harmonic component of the composite torque is decreased by reducing the harmonic component of the resonance order of torque by each cylinder so that the stress in the resonance of the crank shaft or in the vicinity thereof is reduced to avoid the resonance.

In Fig. 1, numeral 26 denotes a detector coupled to a crank shaft of an engine to detect a rotational angle of an engine. Numeral 24 denotes a fuel injection timing setting device which is connected to the detector 26. Numeral 25 denotes a memory which is connected to the fuel injection timing setting device 24. Numerals 23_1 to 23_6 denote actuators each corresponding to each of the cylinders and connected to the fuel injection timing setting device 24. Numerals 22_1 to 22_6 denote control valves each connected to each of the actuators 23_1 to 23_6. Numeral 4 denotes a fuel pump, 3 an accumulator to which the fuel pump 4 is connected. The accumulator and the control valves 22_1 to 22_6 are connected in parallel with each other.

Numerals 1_1 to 1_6 denote fuel injection valves each disposed in each of cylinder heads and opened in a fuel chamber and connected to each of the control valves 22_1 to 22_6.

Operation of the first embodiment is now described.

The detector 26 detects a rotational angle of a crank shaft and a time with the top dead point of a first cylinder as the origin to produce the detected signal. The fuel injection timing setting device 24 receives the signal of the detector 26 and calculates a rotational speed of engine in accordance with the flow chart 1 of the torsional vibration suppressing apparatus of Fig. 6. Whether the rotational speed is within the resonance area of torsional vibration or not is judged on the basis of the contents stored in the memory 25 connected thereto. When it is not within the area, the fuel injection process of normal operation is set for each cylinder and the signal is sent to each of the actuators 23_1 to 23_6. Thus, the actuator 23_1 to 23_6 are operated to actuate the control valves 22_1 to 22_6 so that the fuel injection valves 1_1 to 1_6 normally injects the pressurized fuel stored in the accumulator 3 into combustion chambers of the cylinders.

When the fuel injection timing setting device 24 determines that the rotational speed of the crank shaft is within the resonance range of torsional vibration, the setting device 24 sets an injection timing delay amount common to the cylinders and an injection period extension amount for preventing deterioration of the thermal efficiency and much fuel consumption on the basis of the memory contents of the memory 25 to send signals to the actuators 23_1 to 23_6. Thus, the actuators 23_1 to 23_6 are operated to actuate the control valves 22_1 to 22_6 so that the fuel injection valves 1_1 to 1_6 make uniformly modified fuel injection. The above operations are repeated.

When the rotational speed of engine escapes from the resonance range of torsional vibration, the fuel injection timing setting device 24 can determine that it is not within the resonance range of torsional vibration and accordingly returns to set the normal injection as described above.

A structure of a second embodiment is different only in the contents of the memory from the first embodiment and accordingly description of the structure is omitted.

Operation of the second embodiment is now described.

The six-order harmonic component of torsional vibration of a crank shaft of a series 6-cylinder engine resonates with one-node vibration within the operation range. The resonant state is shown by 16 of the resonance curve of Fig. 4. In Fig. 4, numeral 18 represents an operation avoidance area.

A reason of resonance is as follows:

In the normal operation state, the fuel injection process of the cylinders is relatively identical. Accordingly, the characteristic curve of pressure in the cylinder with respect to the crank angle of the cylinders, the harmonic component of torque of the crank shaft by the cylinders, and the phase from the top dead point of the cylinders are identical. In a harmonic component diagram of Fig. 3, numeral 12 represents the six-order harmonic component of torque of the crank shaft by one cylinder in the normal operation, and numeral 14 represents a phase from the top dead point. Since ignition is at regular intervals in the series six-cylinder engine,

the phase of six-order harmonic component of torque of the crank shaft by the cylinders is just identical. The mode of one-node torsional vibration is as shown by 20 of one-node torsional vibration mode diagram of Fig. 5 and since specific amplitudes 21 in positions of the cylinders have the same direction, the torque component of the same six-order phase excites the vibration strongly.

In the present invention, the fuel injection process of three cylinders of six cylinders is changed and curve 8 in the normal fuel injection shown by the characteristic curve of Fig. 2 is changed to curve 9 shown by broken line of Fig. 2. Thus, the six-order harmonic component of the crank shaft torque is changed as shown by 13 of the harmonic component diagram of Fig. 3 and as shown in Fig. 3 the phase for the top dead point is delayed by about 30° as compared with that shown by 14 of Fig. 3 to reverse the phase as shown by 15 of Fig. 3. Consequently, the torque of the crank shaft by the six cylinders for the one-node torsional vibration mode can be canceled each other to reduce amplitude in the resonance. This is shown by 17 of the resonant curve diagram of Fig. 4. In Fig. 4, numeral 19 denotes an area in which operation must be avoided in the embodiment, while the area is very narrower as compared with the prior art.

Actually, the phase is controlled as follows.

The detector 26 detects the rotational angle and time with the top dead point of the first cylinder of the crank shaft as the origin to produce the signal. The fuel injection timing detector 24 calculates the rotational speed of the crank shaft as shown in the flow chart 2 showing operation of the torsional vibration suppressing apparatus of Fig. 7. Then, it is judged whether the rotational speed of the crank shaft calculated on the basis of the contents of the memory 25 is within the resonant area of torsional vibration or not. When it is determined that it is not within the area, the operation is the same as that of the first embodiment. When it is determined that it is within the area, three cylinders of the six cylinders remain normal while the injection period of three remaining cylinders are set to be delayed by about 30° in common to the three cylinders on the basis of the memory 25 and signals are sent to the actuators 23 corresponding to the three cylinders. Thus, the actuators 23 are operated to actuate the control valves 22 so that the injection valves perform the modified fuel injection. The above process is repeated.

When the rotational speed of the engine escapes from the resonance range of torsional vibration, the fuel injection timing setting device 24 judges it and returns the operation to the normal injection process.

Claims

1. An apparatus for suppressing torsional vibration of a crank shaft of a diesel engine, comprising:

   a detector for detecting a rotational angle of an engine;

   a memory for storing a fuel injection timing in a normal operation and a fuel injection timing in the vicinity of a resonance of torsional vibration; and

   a fuel injection timing setting device supplied with the rotational angle of the engine from said rotational angle detector to calculate a rotational number of the engine and for judging whether the rotational number is within a resonance area of torsional vibration or not so that when the rotational number is within the resonance area of torsional vibration, the fuel injection timing in the resonance of torsional vibration is read out from said memory to inject fuel at the fuel injection timing.

2. An apparatus for suppressing torsional vibration of a crank shaft of a diesel engine, comprising:

   a detector for detecting a rotational angle of an engine;

   a memory for storing a fuel injection timing in a normal operation; and

   a fuel injection timing setting device supplied with the rotational angle of the engine from said rotational angle detector to calculate a rotational number of the engine and for judging whether the rotational number is within a resonance area of torsional vibration or not so that when the rotational number is outside of the resonance area of torsional vibration, the fuel injection timing in the normal operation is set while when the rotational number is within the resonance area of torsional vibration, an injection timing of a half of cylinders is delayed to reduce starting torque in a mode where resonance occurs in torsional vibration so that a phase of the starting torque in the mode by the cylinders is reversed to a phase of starting torque in the mode of remaining cylinders.

3. An apparatus for suppressing torsional vibration of a crank shaft of a diesel engine, according to Claim 2, wherein the number of cylinders is six and the mode where resonance occurs in one-node torsional vibration is a six-order harmonic vibration, and when the rotational number is within the resonance area of torsional vibration, the injection timing for three cylinders is delayed by about 30°.

F I G. I

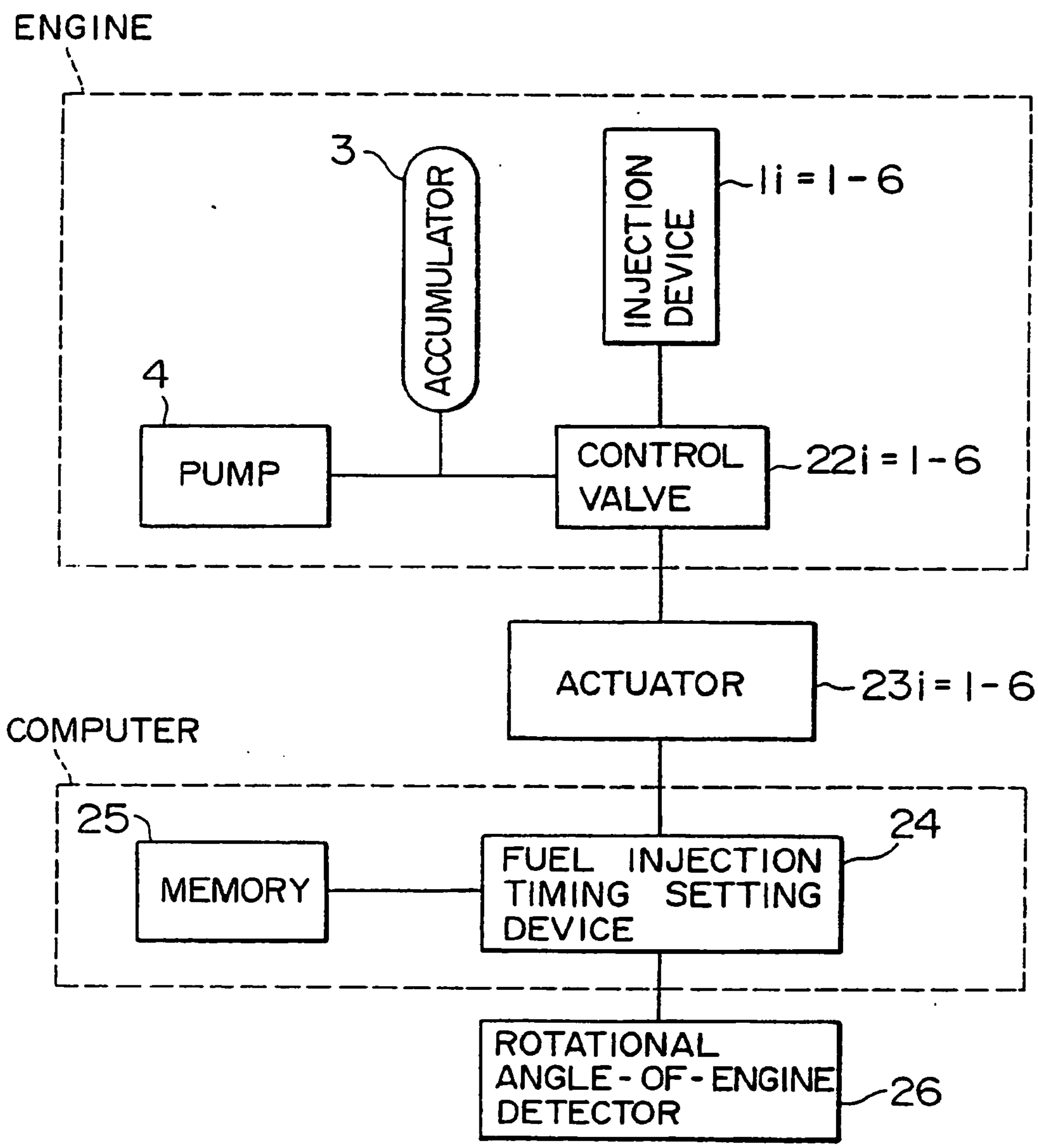

ENGINE
3
ACCUMULATOR
INJECTION DEVICE
Ii = I - 6
4
PUMP
CONTROL VALVE
22i = I - 6
ACTUATOR
23i = I - 6
COMPUTER
25
MEMORY
FUEL INJECTION TIMING SETTING DEVICE
24
ROTATIONAL ANGLE-OF-ENGINE DETECTOR
26

FIG. 2(a)

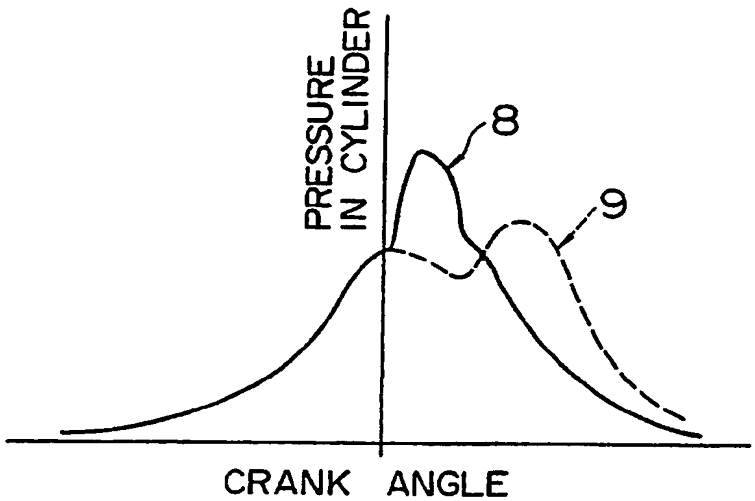

PRESSURE
IN CYLINDER
8
9
CRANK ANGLE

FIG. 2(b)

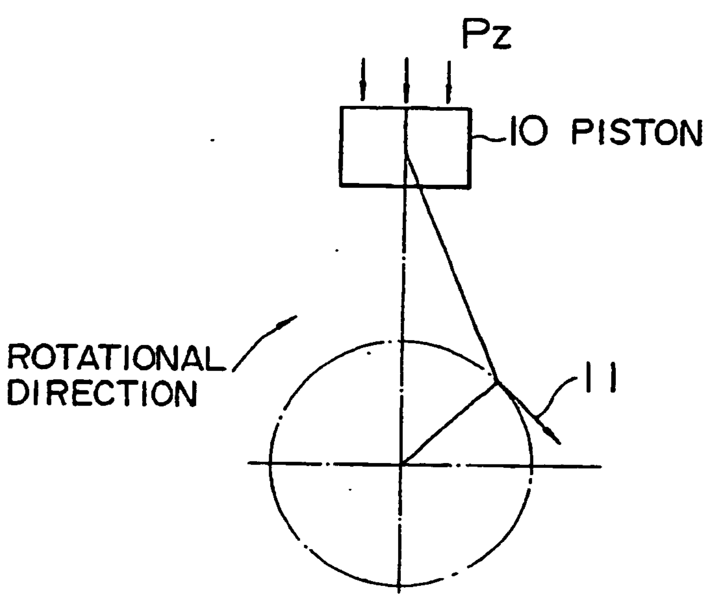

Pz
10 PISTON
ROTATIONAL
DIRECTION
11

FIG. 3

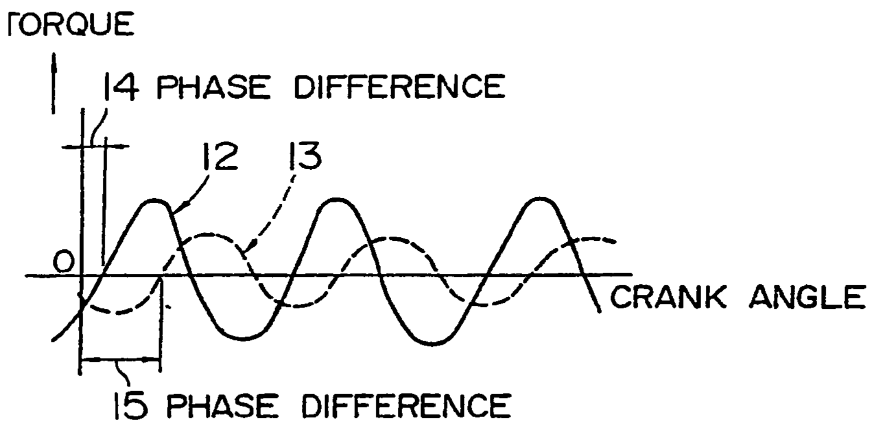
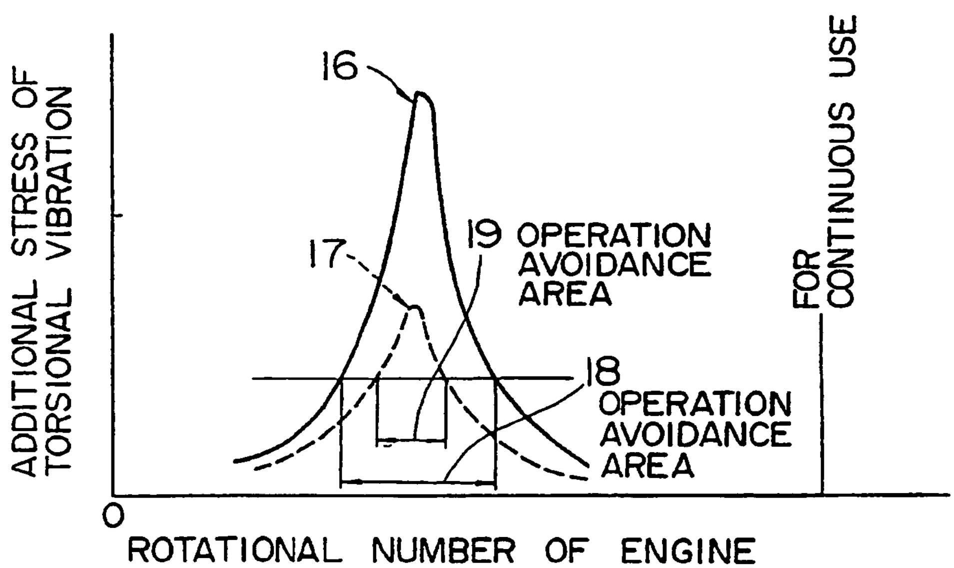
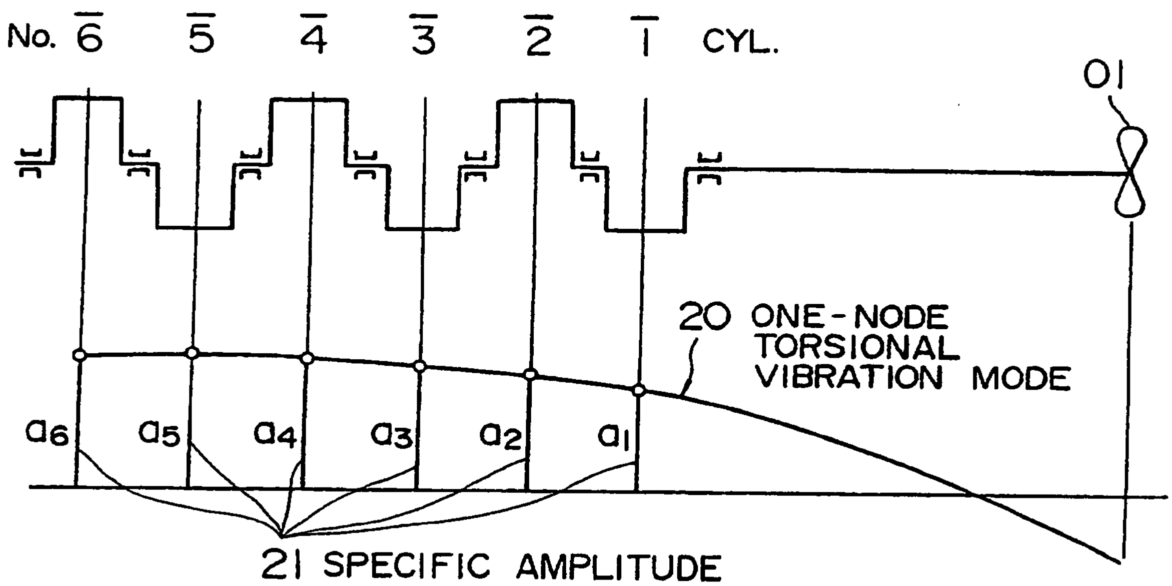

TORQUE
14 PHASE DIFFERENCE
12
13
0
CRANK ANGLE
15 PHASE DIFFERENCE

FIG. 4


ADDITIONAL STRESS OF TORSIONAL VIBRATION
16
17
19 OPERATION AVOIDANCE AREA
18
OPERATION AVOIDANCE AREA
FOR CONTINUOUS USE
0
ROTATIONAL NUMBER OF ENGINE

F I G. 5


No. 6 5 4 3 2 1 CYL.
01
20 ONE-NODE TORSIONAL VIBRATION MODE
a6 a5 a4 a3 a2 a1
21 SPECIFIC AMPLITUDE

F I G. 8

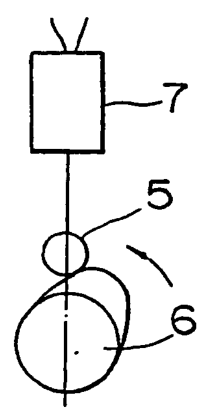

7
5
6

FIG. 6

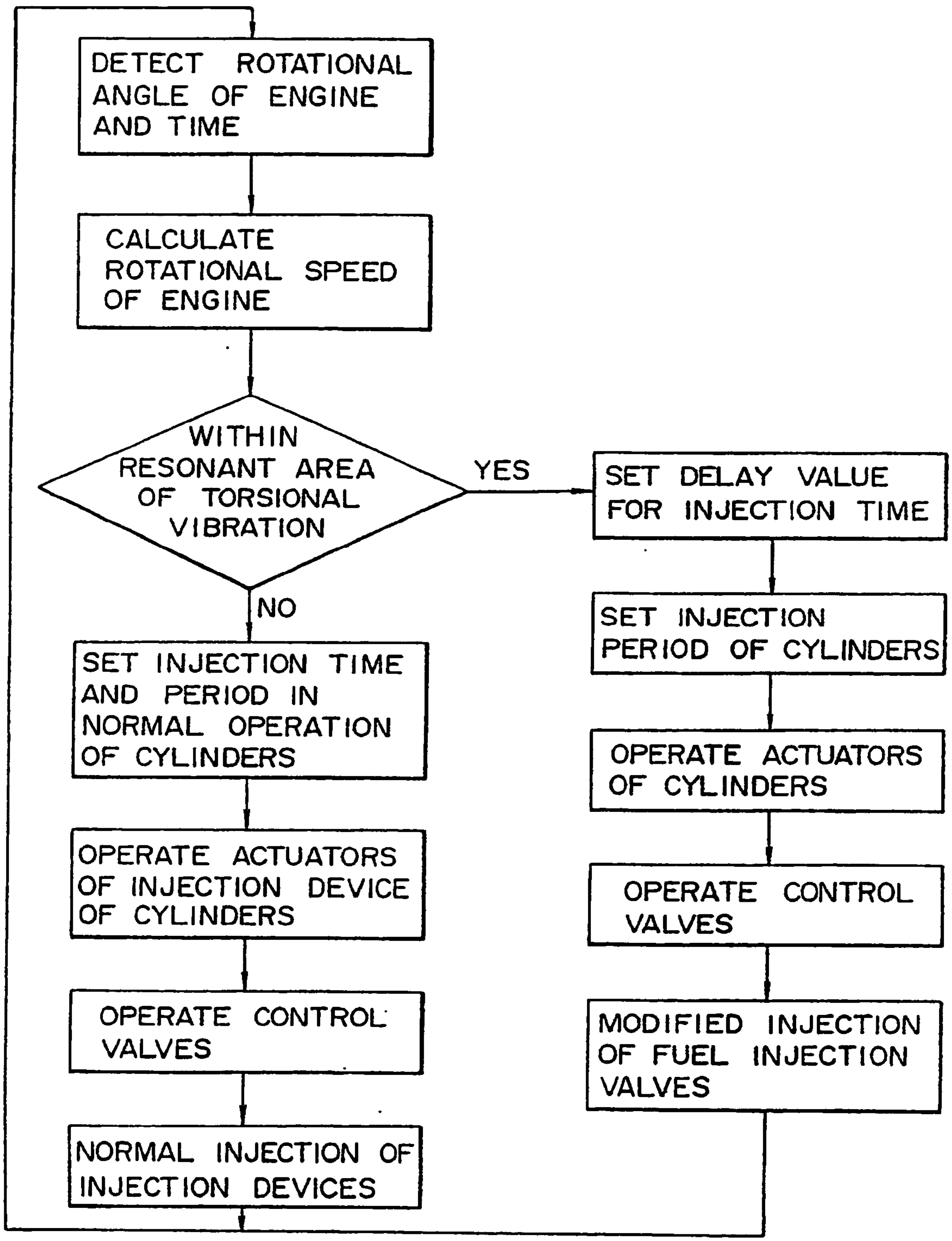
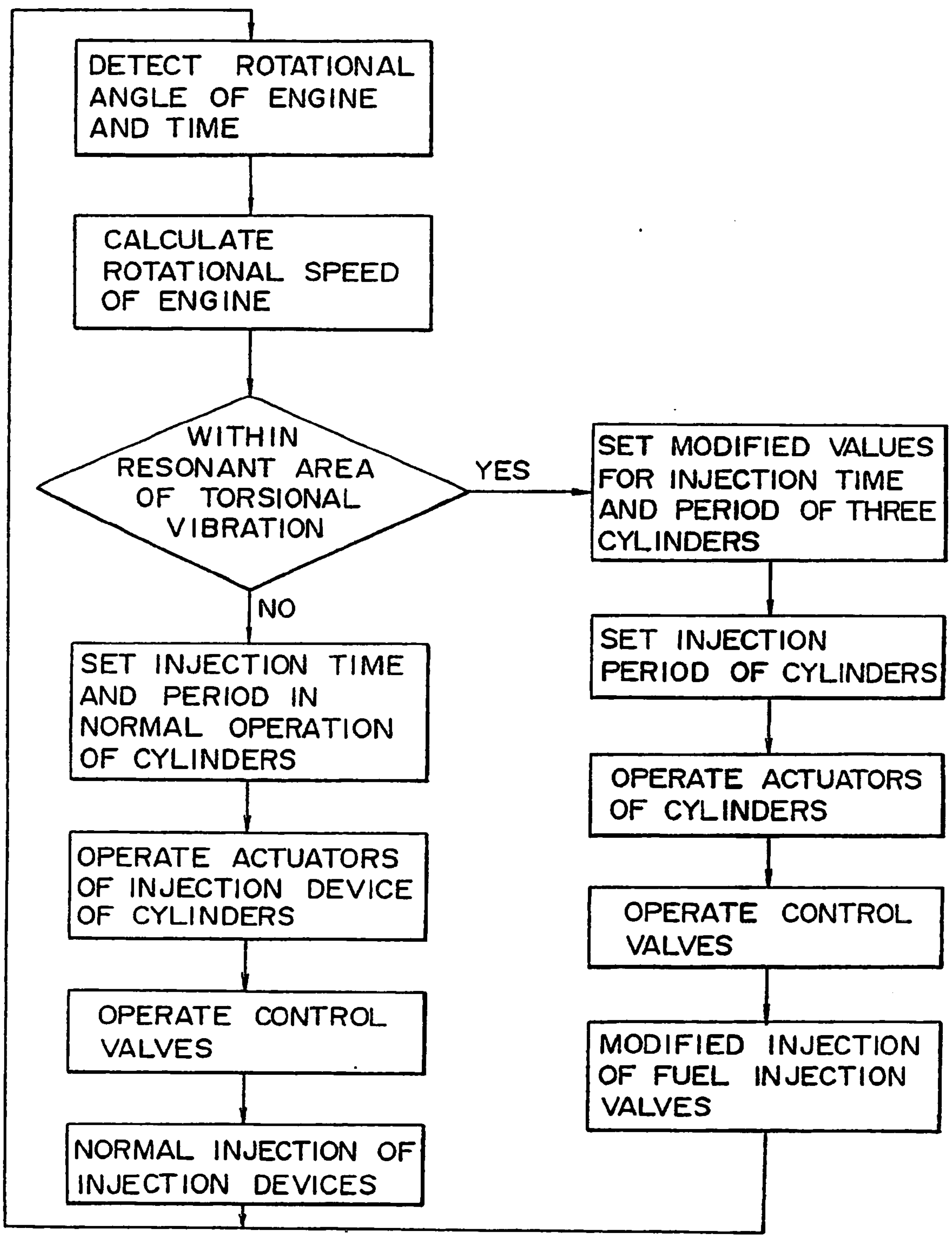

DETECT ROTATIONAL ANGLE OF ENGINE AND TIME
CALCULATE ROTATIONAL SPEED OF ENGINE
WITHIN RESONANT AREA OF TORSIONAL VIBRATION
YES
NO
SET DELAY VALUE FOR INJECTION TIME
SET INJECTION PERIOD OF CYLINDERS
OPERATE ACTUATORS OF CYLINDERS
OPERATE CONTROL VALVES
MODIFIED INJECTION OF FUEL INJECTION VALVES
SET INJECTION TIME AND PERIOD IN NORMAL OPERATION OF CYLINDERS
OPERATE ACTUATORS OF INJECTION DEVICE OF CYLINDERS
OPERATE CONTROL VALVES
NORMAL INJECTION OF INJECTION DEVICES

FIG. 7


DETECT ROTATIONAL ANGLE OF ENGINE AND TIME
CALCULATE ROTATIONAL SPEED OF ENGINE
WITHIN RESONANT AREA OF TORSIONAL VIBRATION
YES
NO
SET MODIFIED VALUES FOR INJECTION TIME AND PERIOD OF THREE CYLINDERS
SET INJECTION PERIOD OF CYLINDERS
OPERATE ACTUATORS OF CYLINDERS
OPERATE CONTROL VALVES
MODIFIED INJECTION OF FUEL INJECTION VALVES
SET INJECTION TIME AND PERIOD IN NORMAL OPERATION OF CYLINDERS
OPERATE ACTUATORS OF INJECTION DEVICE OF CYLINDERS
OPERATE CONTROL VALVES
NORMAL INJECTION OF INJECTION DEVICES

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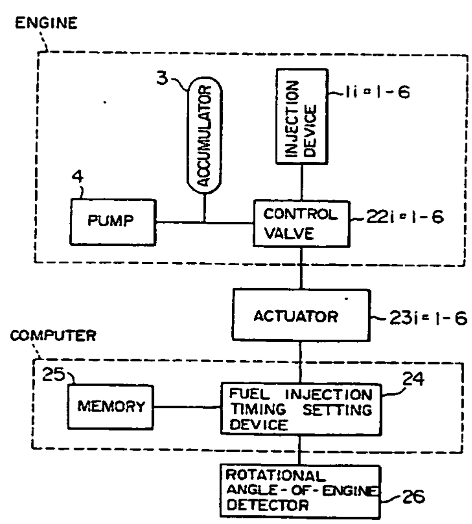
F I G. 1



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EUROPEAN SEARCH REPORT

Application Number

EP 90 25 0320

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
Y	EP-A-0 107 523 (THE BENDIX CORP.) * page 1, line 15 - line 20 * * * page 6, line 20 - page 7, line 2 * * * page 13, line 1 - page 14, line 5 * *	1-3	F 02 D 41/14 F 02 D 41/34
Y	US-A-4 172 434 (COLES) * column 2, line 35 - line 60 * * * column 4, line 54 - column 6, line 7 * * * column 8, line 1 - line 24 * * * column 12, line 8 - line 15 * *	1-3	
A	PATENT ABSTRACTS OF JAPAN vol. 9, no. 149 (M-390)(1872) 25 June 1985 & JP-A-60 026 142 (TOYOTA JIDOSHA K.K.) 9 February 1985 * abstract * *	1-3	
A	US-A-4 572 130 (TSUKAMOTO ET AL.) * column 1, line 25 - column 4, line 31 * *	1-3	
A	EP-A-0 254 005 (GEBRÜDER SULZER AKTIENGESELL-SCHAFT) * the whole document * *	1	
A	US-A-4 418 669 (JOHNSON ET AL.)	1	

TECHNICAL FIELDS SEARCHED (Int. Cl.5)
F 02 D

The present search report has been drawn up for all claims

Place of search	Date of completion of search	Examiner
The Hague	18 December 91	MOUALED R.

CATEGORY OF CITED DOCUMENTS

X: particularly relevant if taken alone
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